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# Parametric Study on Diagrid Structural System with and without Shear Walls

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***Abstract*— *Among the various lateral load resisting systems of the tall structures, diagrid structural system is a unique structural system and found effective compared to other bracing systems, which is increasingly popular from the past decades. The diagrids are perimeter structural configurations characterized by a grid of diagonal members which are involved both in gravity and in lateral load resistance. The diagrid structure ensures the overall stiffness and strength of the building only engaging the diagonal members in a purely axial behaviour and fully braces the interior gravity columns for stability only at joints of diagrid. The intermediate floors, are not laterally restrained by the global behaviour of the diagrid system, means if diagonals are continuous throughout the module height, the floors would derive a certain degree of lateral stiffness only from the flexural stiffness of the diagrids. Although diagrid system is good enough to perform well in lateral load resisting compare to other simple frame and shear wall building, we can combined the diagrid structure with shear walls for optimum design. The present study aimed to understand the behaviour of the diagrid structural system with shear walls at core. For this study a regular square plan of 30m × 30m diagrid structure considering different storey module (i.e. 4, 6, 8 & 12) with and without core Shear Walls is modelled and analyzed. For minimum displacement and drift different plan shape of shear wall are taken and one of them with optimum results is used for further analysis. Then behaviour of diagrid structure with and without shear wall along the height is also studied considering 24, 36 and 48 storey. ETABS software is used for modelling and analysis. Parameters such as inter storey drift-ratio, storey displacement, base shear and reduction in lateral load on diagrid are taken into consideration.*

***Keywords*— Diagrid structure, Inter storey drift ratio, Shear wall, Storey module, Storey displacement, Tall building.***

## I. INTRODUCTION

The lateral loading due to wind and earthquake is governing factor that causes the design of high-rise buildings. These lateral loads are resisted structural by different structural system provided. The lateral load resisting systems that are used mainly shear wall, wall-frame, braced tube system, outrigger system, diagrid system and tubular system.

Diagrid is an exterior structural system in which all perimeter vertical columns are removed and replaced by inclined columns on which is called diagrids. Shear and over-turning moment developed due to lateral loads are resisted by axial action of these diagonals. As most diagrid structures have core as partial lateral stability. The diagrid structure is an extension of the tube-in-tube structure, where the outer tube is comprised of diagrids. There is bit confusion between the conventional exterior braced frame structure and diagrid structure but the major difference between them is that in a diagrid structure, peripheral columns are eliminated. This is because in diagrid structures, diagrids are also takes the gravity load in addition to the lateral load by triangulated configuration, while the conventional bracing system could not take any gravity load.[14]

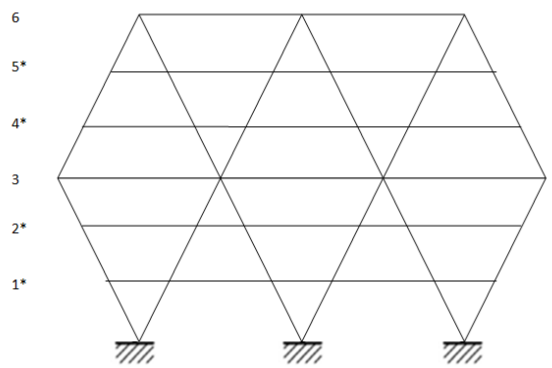
Structural systems of tall buildings can be divided into two broad categories: core structures and exterior/peripheral structures, which is based on the distribution of the components of the primary lateral load-resisting system over the building. A system is categorized as an core structure when the major part of the lateral load resisting system is located at core of the structure. Similarly, if the major part of the lateral load-resisting system is located at the perimeter of structure, a system is called as an exterior structure.[11]

The major types of lateral load-resisting systems in category of core structures are the moment-resisting frames and shear walls. These systems are usually arranged as planar assemblies in two principal orthogonal directions and may be used as a combined system. The building perimeters has more structural significance in tall buildings due to their very tallness, which means greater vulnerability to lateral forces, especially wind loads. Therefore, it is quite desirable to concentrate as much lateral load-resisting system components as possible on the perimeter of tall buildings to increase their structural depth, and, in turn, their resistance to lateral loads.[11]

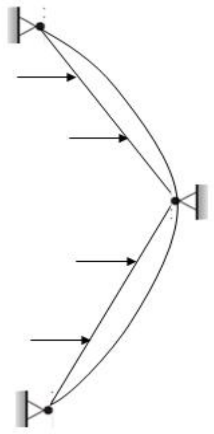
The design of the modules comes first among the items to be decided while planning the diagrid structure. The criteria for design of the modules are the suitability of the gap angle, topographic conditions, strength, height of the structure, loads, etc. How many floors there will be between node numbers of each modules, the angle and dimensions of the structural tubes vary as per requirements of design.[12]

### 1.1 Drawbacks (Local issue) of Diagrid Structural System

The structural behaviour of systems with mega-diagonals could be assimilated to a vertical truss with panel points (diagrid nodes) located multiple floors apart in Fig.1.1(a)[7] is sketched a typical diagrid system. The diagrid structure ensures the global stiffness and strength of the overall building by considering diagonal members as truss member in design(purely axial behaviour) and braces the interior gravity columns for stability only at panel points. The intermediate floors in Fig. 1.1(a)[7], are not laterally restrained by the global behaviour of the diagrid system; in other words, if diagonals are continuous throughout the module height, the floors would derive a certain degree of lateral stiffness only from the flexural stiffness of the diagonals Fig. 1.1(b).[7]



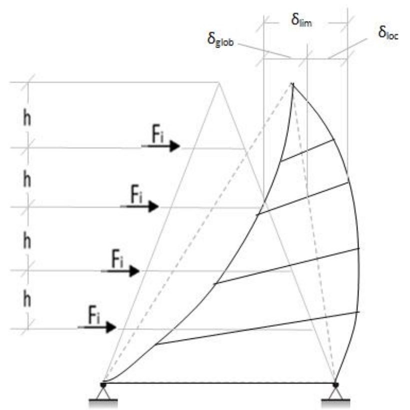

**(a)**



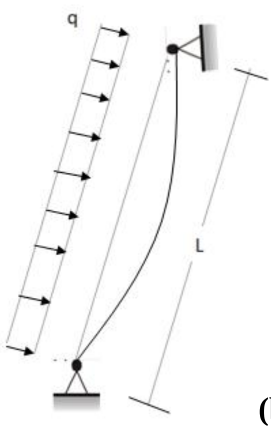
**(b)**

*Fig. 1: (a) Typical diagrid system (b) Mega-diagonal elements between panel points.[7]*

Within given the module height, the diagrid members provide a partial lateral restraint with the help of their flexural stiffness. This partial restraining could be or not sufficient to brace the internal columns, activating a single floor buckling mode, and to limit inter storey drifts.[7]




**(a)**




**(b)**

*Fig. 2: (a) Lateral deformation of diagrid module (b) The diagrid diagonals under horizontal forces.[7]*

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## II. METHODOLOGY

First step is to find optimum plan shape/placement of shear wall at core, for which parameters such as displacement and inter- drift ratio is taken into consideration. For this RC bare frame structure with four different placement/plan shape shear walls at core is taken and analysis is carried out and lateral loads (Seismic and Wind) are considered.

After analysis, one case with optimum/minimum displacement and inter- drift ratio will taken into consideration for further analysis for diagrid structure with and without shear walls.

In second part of work diagrid structure with four different module (i.e. 4, 6, 8, 12 module ; Angle of diagrid θ= 67.38°, 74.47°, 78.23°, 82.09° respectively) taken into consideration with and without shear walls at core of structure. Each case is also analyzed with three different height (i.e. 24 , 36 and 48 ).

Square RC framed structure with steel pipe section diagrids at periphery is considered for modeling. Lateral loads are seismic and winds are taken into consideration as per Indian Standard codes IS 1893 (Part 1) : 2016 and IS 875 (Part 3) : 2015 respectively.

### 2.1 Placement/Plan-Shape of Shear Wall At Core

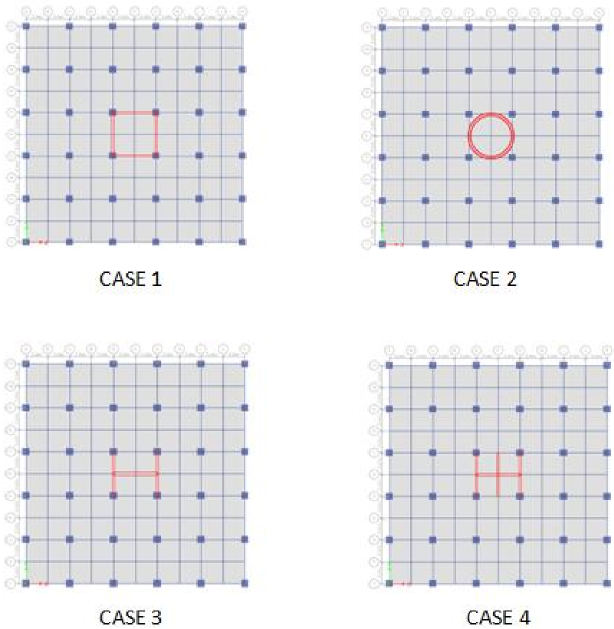



*Fig. 3: Shear Walls at core (a) Case 1 (b) Case 2 (c) Case 3 (d) Case 4*

### 2.2 Diagrid Structure with and Without Shear Walls

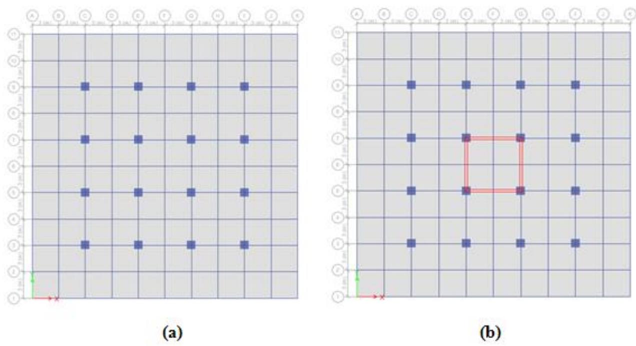



*Fig.4 : Plan of Building (a) without shear wall (b) with shear wall*

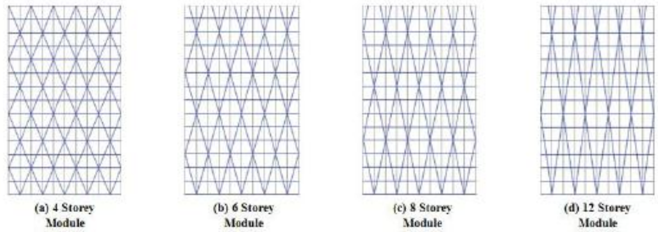



*Fig.5: 4, 6, 8 and 12 storey diagrid Module*

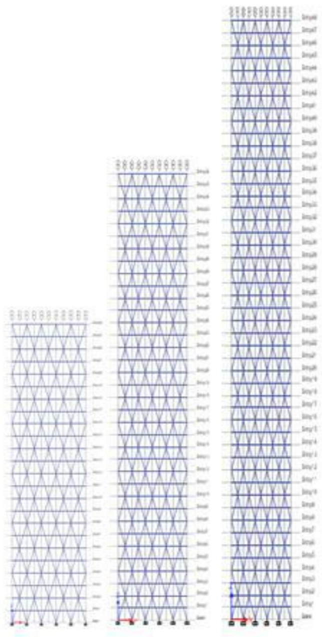


*Fig. 6: 4 Module : 24, 36, 48 Storey*

## III. GEOMETRIC DATA

*Table 1: Model Details*

| | | |
|---|---|---|
| PLAN | 30m × 30m | |
| HEIGHT | 3.6m | |
| | | |
| MEMBER SIZE | BEAM | 300mm X 500mm |
| | SLAB | 120mm |

| | | |
|---|---|---|
| | SHEAR WALL | 250mm |
| | | |
| MATERIAL TYPE | CONCRETE | BEAM-M30 |
| | | COLUMN-M40 |
| | | SLAB-M30 |
| | | SHEAR WALL-M30 |
| | STEEL | REBAR-HYSD 500 |
| | | DIAGRID-Fe345 |
| | | |
| LOAD | DEAD(FF) | 1.0 KN/m$^2$ |
| | LIVE | 3.0 KN /m$^2$ |
| | | |
| MATERIAL DENSITY | CONCRETE | 25kN/m$^3$ |
| | STEEL | 78.5kN/m$^3$ |
| | | |
| SOIL TYPE | MEDIUM OR STIFF SOILS | |
| RESPONSE REDUCTION FACTOR (R) | 5 | |
| IMPORTANCE FACTOR (I) | 1.2 | |
| ZONE | III | |
| | | |
| BASIC WIND SPEED | 39 m/s | |
| TERRAIN CATEGORY | III | |

*Table 2 : Column section details for 24, 36, 48 storey height*

| STOREY | SECTION SIZE |
|---|---|
| 24 | 950mm X 950mm |
| 36 | 1150mm X 1150mm |
| 48 | 1350mm X 1350mm |

*Table 3 :Diagrid (Diagonal) pipe section details*

| STOREY | MODULE | SECTION SIZE (OUTER DIAMETER-THICKNESS) |
|---|---|---|
| 24 | 4 | 350 mm - 15mm |
| | 6 | 400 mm - 20mm |
| | 8 | 450 mm - 25mm |
| | 12 | 550 mm - 30mm |
| 36 | 4 | 350 mm - 25mm |
| | 6 | 420 mm - 25mm |
| | 8 | 500 mm - 25mm |
| | 12 | 620 mm - 30mm |
| 48 | 4 | 370 mm - 30mm |
| | 6 | 450 mm - 30mm |
| | 8 | 550 mm - 40mm |
| | 12 | 650 mm - 40mm |

*Table 4 : Nomenclature for cases considered*

| STOREY/ MODULE | 4 | 6 | 8 | 12 |
|---|---|---|---|---|
| 24 | A1 | A2 | A3 | A4 |
| 36 | B1 | B2 | B3 | B4 |
| 48 | C1 | C2 | C3 | C4 |

## IV. RESULT AND DISCUSSION

### 4.1 Placement/Plan-Shape Of Shear Wall At Core

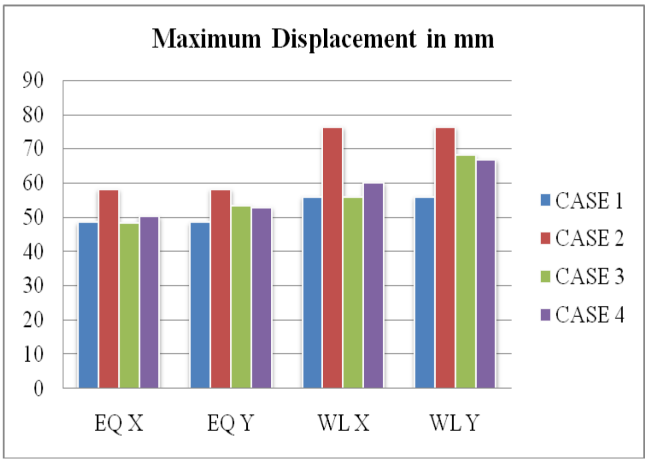



*Fig. 7: Maximum Story Displacement in mm*

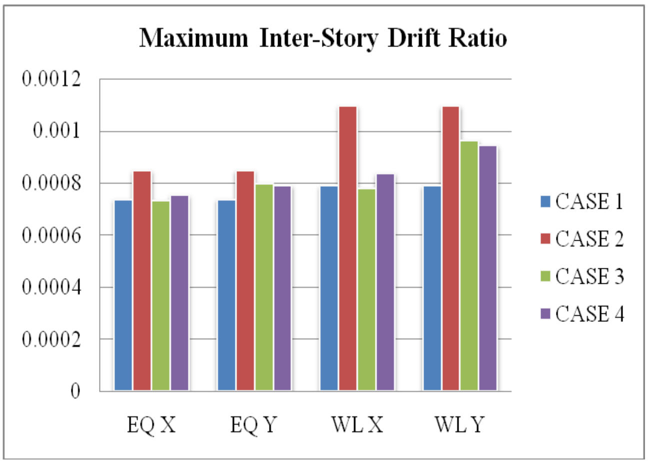
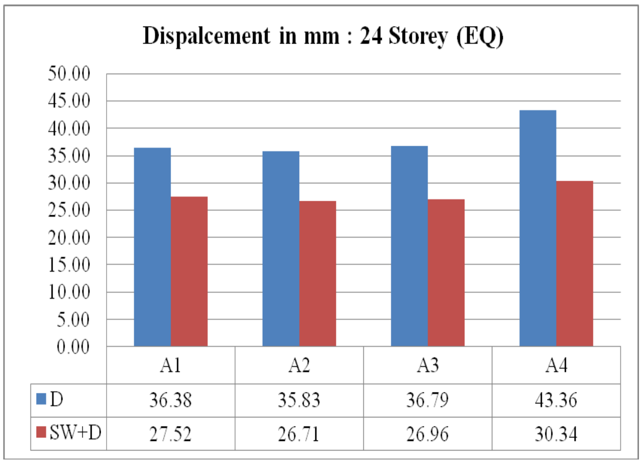



*Fig. 8: Maximum Inter-Story Drift Ratio*

Results and plot of displacement and inter-storey drift ratio are showing that Case 1 which is square box type placement of shear wall at core is having minimum displacement and inter drift ratio in both directions and also in seismic and wind loads. Therefore shear wall of Case 1 (square) will be used for diagrid structure modeling with shear walls at core for optimum results.

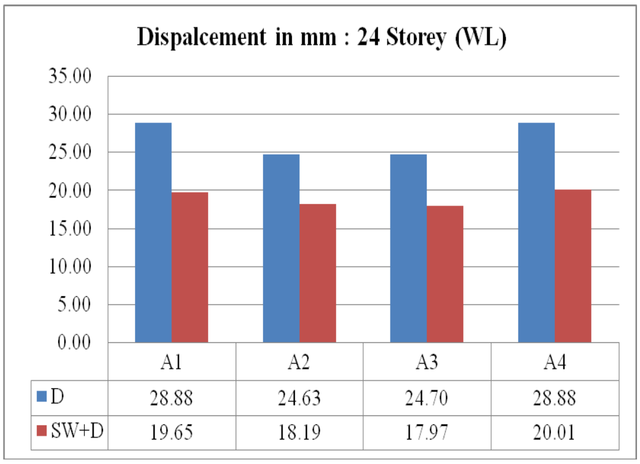
### 4.2 Diagrid Structure With And Without Shear Walls

4.2.1 Maximum Displacement Results



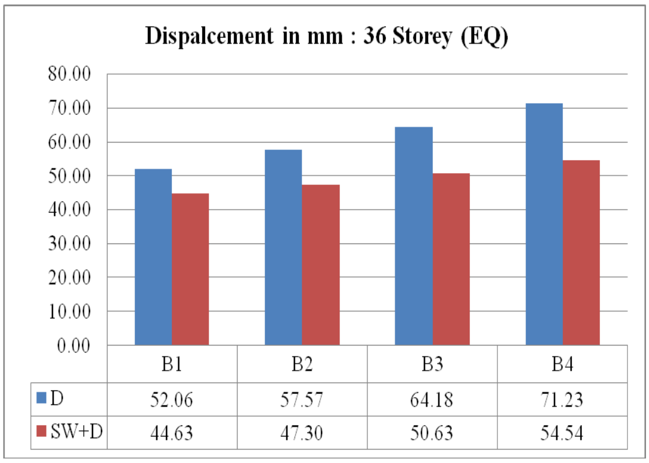

| | A1 | A2 | A3 | A4 |
|---|---|---|---|---|
| D | 36.38 | 35.83 | 36.79 | 43.36 |
| SW+D | 27.52 | 26.71 | 26.96 | 30.34 |

*Fig. 9: Maximum Story Displacement in mm 24 Storey*



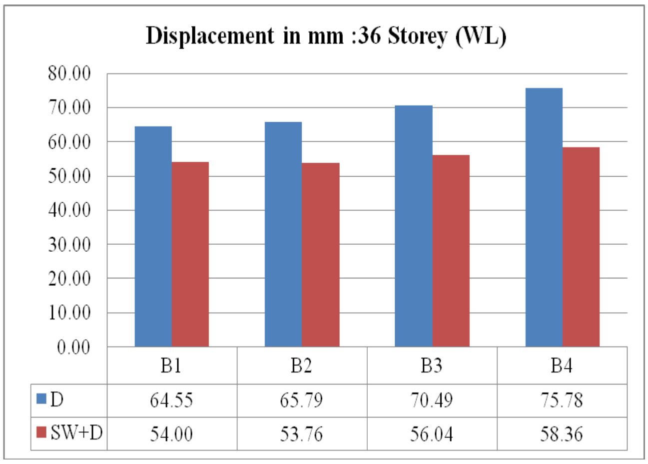

| | A1 | A2 | A3 | A4 |
|---|---|---|---|---|
| D | 28.88 | 24.63 | 24.70 | 28.88 |
| SW+D | 19.65 | 18.19 | 17.97 | 20.01 |

*Fig. 10: Maximum Story Displacement in mm 24 Storey*



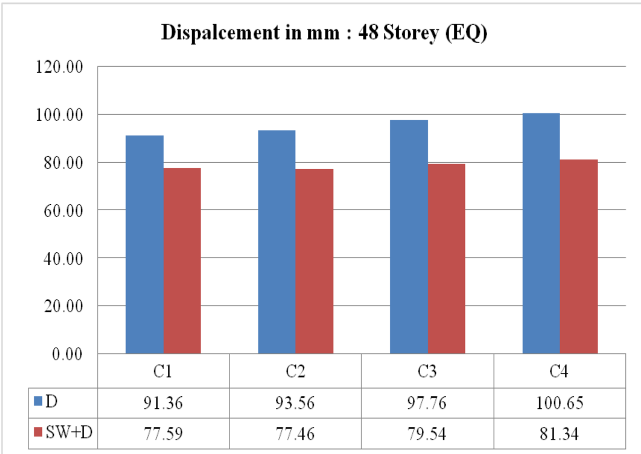

| | B1 | B2 | B3 | B4 |
|---|---|---|---|---|
| D | 52.06 | 57.57 | 64.18 | 71.23 |
| SW+D | 44.63 | 47.30 | 50.63 | 54.54 |

*Fig. 11: Maximum Story Displacement in mm 36 Storey*




| | B1 | B2 | B3 | B4 |
|---|---|---|---|---|
| D | 64.55 | 65.79 | 70.49 | 75.78 |
| SW+D | 54.00 | 53.76 | 56.04 | 58.36 |

*Fig. 12: Maximum Story Displacement in mm 36 Storey*




| | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| D | 91.36 | 93.56 | 97.76 | 100.65 |
| SW+D | 77.59 | 77.46 | 79.54 | 81.34 |

*Fig. 13:Maximum Story Displacement in mm 48 Storey*

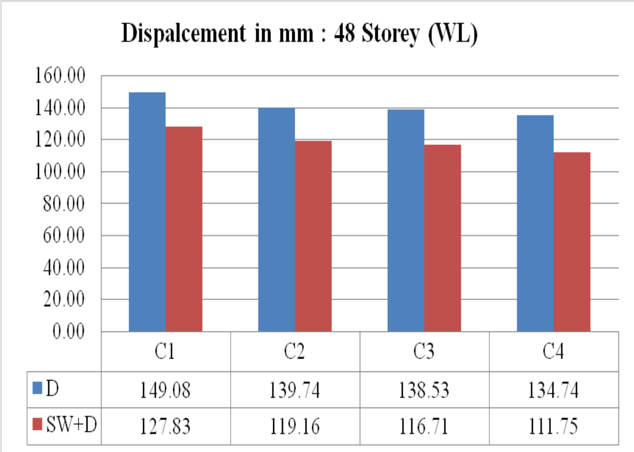



*Fig. 14: Maximum Story Displacement in mm 48 Storey*

4.2.2 Inter Drift Ratio Results

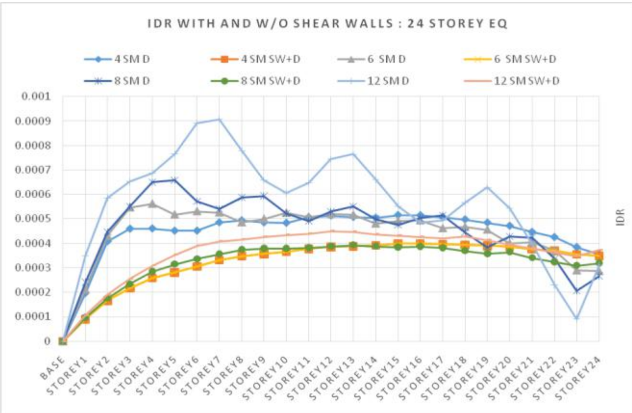



*Fig. 15: Inter storey drift ratio : 24 storey (EQ)*

As mentioned above within the diagrid storey module intermediate floors are partialy restrained and having less storey stiffness which results in high inter storey drift ratio, but after providing shear wall at core, that increases the stiffness and imparts the lateral stability with help of their large in plane stiffness. From results it is clear that in almost all the cases of diagrid structure, major issue is of excessive inter storey drift ratio, which is eliminated with help of shear walls at core.

4.2.3 Percentage Reduction In Maximum Inter Drift Ratio

*Table 4: Reduction in maximum IDR(%)*

| EQ | | | |
|---|---|---|---|
| | 24 Storey | 36 Storey | 48 Storey |
| 4 Module | 22.52 | 13.41 | 13.83 |
| 6 Module | 29.00 | 16.91 | 15.71 |
| 8 Module | 40.43 | 24.03 | 17.72 |
| 12 Module | 50.33 | 37.43 | 21.98 |
| WL | | | |
| | 24 Storey | 36 Storey | 48 Storey |
| 4 Module | 53.18 | 13.81 | 12.65 |
| 6 Module | 35.41 | 17.30 | 12.43 |
| 8 Module | 42.57 | 26.27 | 14.66 |
| 12 Module | 49.74 | 37.07 | 24.93 |

It is found that shear walls at core in diagrid structure will almost eliminate the local stability and flexibility issue within the diagrid module. This happens because when shear walls are provided at core due to their large in plane stiffness they increase the stiffness of overall diagrid structure and not only at node points.

From result and plot of percentage reduction in maximum inter drift ratio it is found that decrement in inter drift with increase in module, increases significantly and in steep angle diagrid building it is giving maximum reduction.

4.2.4 Reduction In Reaction On Diagrid

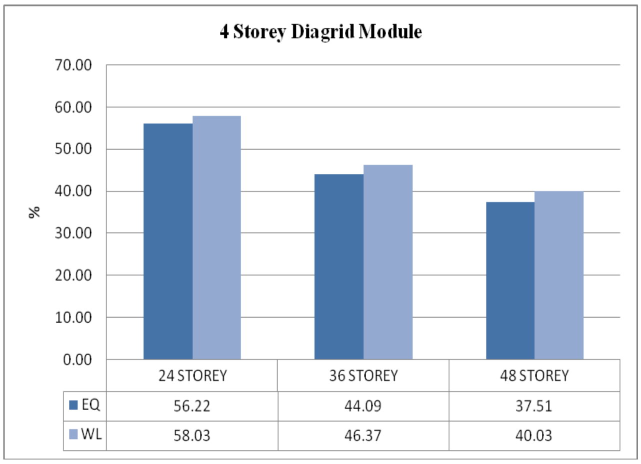



*Fig. 16: 4 Story diagrid module*

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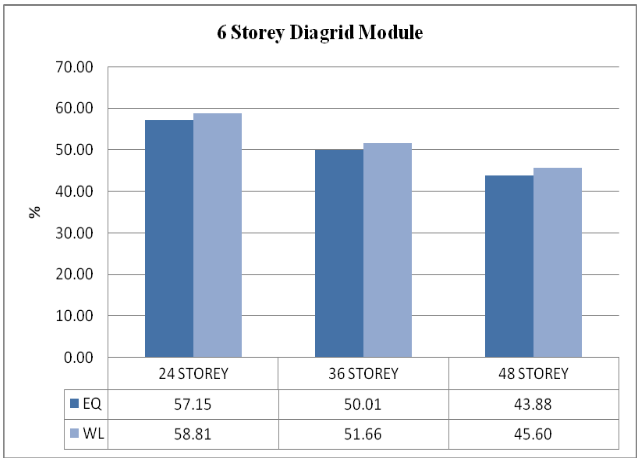


*Fig. 17: 6 Story diagrid module*

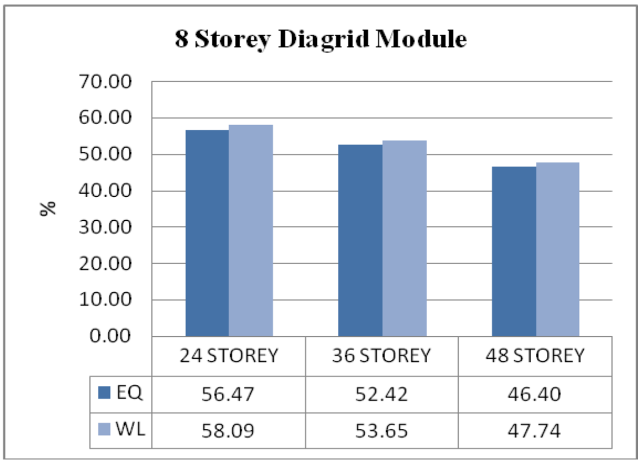


*Fig. 18: 8 Story diagrid module*

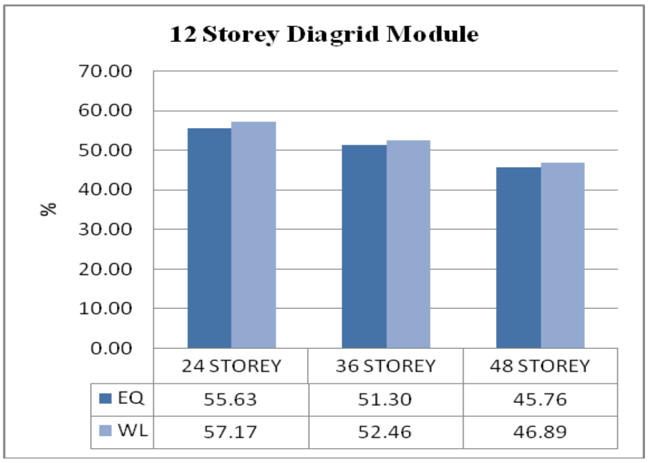


*Fig. 19: 12 Story diagrid module*

4.2.5 Base Shear With & Without Shear Wall under EQ

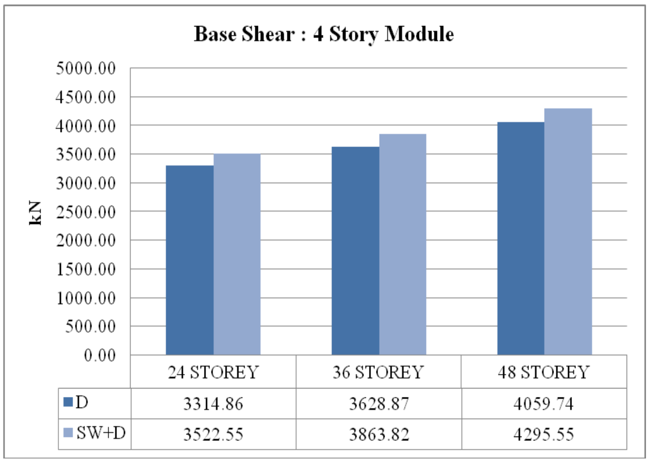


*Fig. 20: Base shear 4 Story Module*

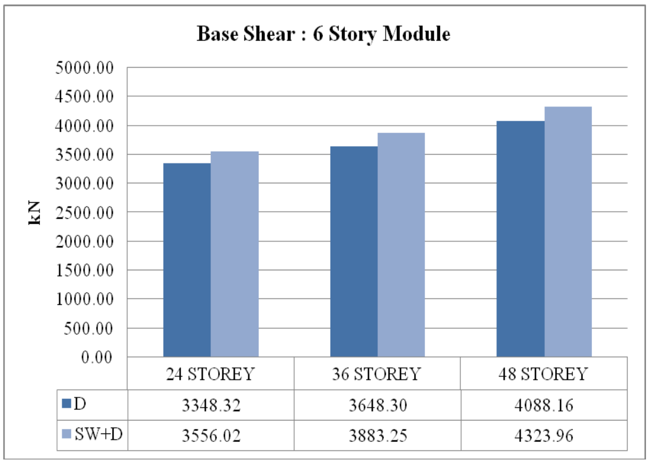


*Fig. 21: Base shear 6 Story Module*

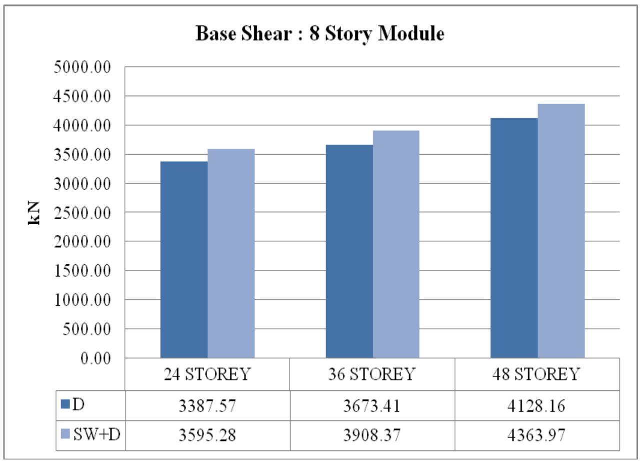


*Fig. 22: Base shear 8 Story Module*

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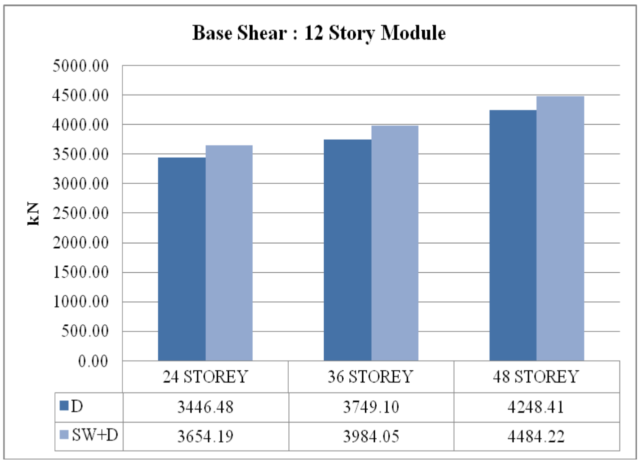


*Fig. 23: Base shear 12 Story Module*

4.2.6 Percentage Increase In Quantity With Shear Wall

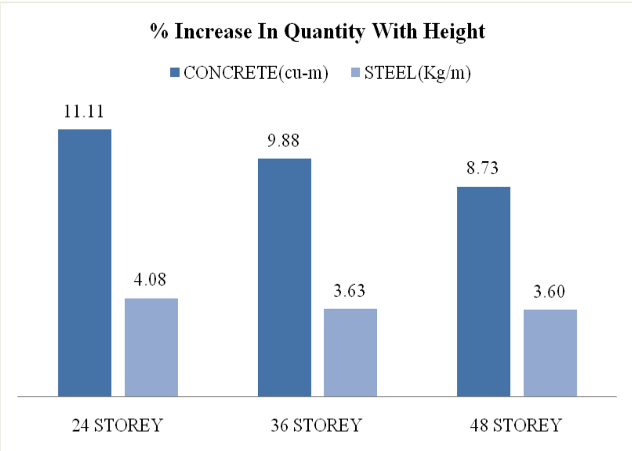


*Fig. 24: % Increase In Quantity With Shear Wall*

## V. CONCLUSION

In this paper a regular square plan of 30m × 30m diagrid structure considering different storey module (i.e. 4, 6, 8 & 12) with and without core Shear Walls is analysed and 24, 36 and 48 storey buildings are also considered. Parameters such as inter storey drift-ratio, storey displacement, base shear and reduction in lateral load on diagrid are taken into consideration.

- As results shows incorporation of shear walls at core of the diagrid structure is advantageous in many ways with very small increase in material quantity.
- By providing shear wall at core of diagrid structure maximum displacement reduced by 15-30% and maximum inter-storey drift ratio reduced by 15-50% (Higher decrement observed as the storey module increase) under both seismic and wind load.
- Shear walls almost eliminate the local stability issue and also eliminate the problem of large inter storey drift within storey module, by increasing the stiffness of structure.
- Shear wall takes most of lateral loads and results in reduction in load on diagrid about almost half (45%-55%) compared to structure without shear wall.
- By incorporation of shear wall at core of diagrid structure, the increase in base shear is around 5 to 6% and material quantity is around 8-11% for concrete and 3-4% for steel which is considerably small.
- Further, shear wall takes 30% to 65% of lateral loads which reduces the lateral loads on diagrid at periphery which ultimately results in economical diagrid section compared to diagrid structure without shear walls at core.
- As per studies with increase in diagrid angle (higher storey module), material requirement for diagrid is less and for those structure inter storey module drift are large and stiffness reduced significantly therefore if shear wall is provided than large inter-storey drift and displacement are reduced and stiffness will increase.

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